Instruction Handbook for...

Type 72

Automatic NOISE-FIGURE INDICATOR

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INSTRUCTION HANDBOOK FOR
AIL TYPE 72
AUTOMATIC NOISE-FIGURE INDICATOR

June 1957

AIRBORNE INSTRUMENTS LABORATORY, INC.
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TABLE OF CONTENTS

	Page
Section I. General Description	1
1. Purpose and Applications	1
2. Specifications	1
3. Description of Equipment	2
Section II. Operation	3
1. Interconnections	3
2. Automatic Noise-Figure Measurement	3
3. Manual Noise-Figure Measurement	4
4. Checks and Adjustments	4
5. Precautions	6
Section III. Theory of Operation	8
1. General	8
2. Gas-Discharge Lamp	9
3. Y Factor	9
4. Noise-Lamp Modulator	10
5. Modulation Frequency and Narrow-Band Filter	11
6. Circuit Description	12
Section IV. Maintenance	16
1. Noise Generator	16
2. Automatic Noise-Figure Indicator	16
3. I-F and Video Amplifier	16
4. Switching Circuits	17

LIST OF ILLUSTRATIONS

Figure	
1	AIL Type 72 Automatic Noise-Figure Indicator
2	Automatic Noise-Figure Indicator, Functional Block Diagram
3	Typical Bench Setup Using Automatic Noise-Figure Indicator and Noise Generator for Automatic Noise-Figure Measurement
4	Bench Setup for Manual Noise-Figure Measurement
5	Y Factor vs Noise Figure for 15.28-db Noise Source
6	Reduction in Excess Noise Power Output as a Function of Fired Insertion Loss
7	Automatic Noise-Figure Measuring Equipment, Schematic Diagram

SECTION I
GENERAL DESCRIPTION

1. PURPOSE AND APPLICATIONS

The AIL Type 72 Automatic Noise-Figure Indicator (Figure 1) is intended primarily for the automatic monitoring of noise figures of receivers, tuners, and other equipment during actual operation. The effects of adjustments and modifications of the equipment under test can thus be immediately observed. The instrument is completely automatic and requires no auxiliary equipment or interpolations for operation.

Another important application of the Automatic Noise-Figure Indicator is its use as a precision receiver for relative-gain measurements. With the addition of a calibrated attenuator (such as the AIL Type 30), quick measurements of power-level differences up to 80 db can be made.

2. SPECIFICATIONS

Range of noise-figure measurement	0 to 20 db
Accuracy	±0.5 db
Minimum required gain of equipment under test (approximately)	40 db*
I-F center frequency	As specified
I-F bandwidth	As specified
I-F input impedance	50 ohms
Power supply	115 volts; 50 to 60 cps
Dimensions	12 X 13-1/2 X 26 inches
Weight	55 pounds

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* The AGC circuits will regulate receiver gain down to a c-w input of 100 μv at i-f center frequency. An equivalent amount of noise must be supplied to the i-f input of the Automatic Noise-Figure Indicator in order to maintain its calibration.

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3. DESCRIPTION OF EQUIPMENT

Figure 2 is a functional block diagram of the Noise-Figure Indicator; the block diagram also shows one of the AIL Type 70 series of Noise Generators. The complete unit can be divided functionally into two main units: the noise source (consisting of an argon gas-discharge lamp and mount, a low-frequency oscillator, and a square-wave modulator) and the noise-figure measuring equipment (consisting of a gain-controlled i-f amplifier, detector, video amplifier, narrow-band filter, and indicating meter). The noise generator is coupled to the receiver or other piece of equipment under test. The i-f output of the equipment under test feeds the i-f amplifier of the Automatic Noise-Figure Indicator. In the indicator the square-wave modulated noise signal is amplified in a gain-controlled i-f amplifier, detected, further amplified in a video stage, and fed (through a narrow-band filter and a cathode follower) to a meter that is calibrated directly in decibels of noise figure.

SECTION II
OPERATION

1. INTERCONNECTIONS

There are four simple steps in setting up the Automatic Noise-Figure Indicator for an automatic noise-figure measurement. These steps are (see Figure 3):

1. Connect the Automatic Noise-Figure Indicator to a 115-volt 60-cps source (a minimum warm-up time of 15 minutes is recommended).
2. Connect the high-voltage cables to the Noise Generator.
3. Connect the output of the Noise Generator to the input of the receiver or other equipment to be tested (this includes proper termination of the Noise Generator).
4. Connect the i-f output of the equipment under test to the i-f input of the Automatic Noise-Figure Indicator.

2. AUTOMATIC NOISE-FIGURE MEASUREMENT

Automatic measurement of noise figure is made in the following manner.

1. Push the POWER ON button; wait for the instrument to warm up.
2. Push the DET. CURRENT AGC ON button. In this position of the button, the meter reads the rectified second detector current at the output of the i-f amplifier. The meter should read about 0.5 ma, indicating proper AGC action. (The AGC circuits will regulate receiver gain down to a c-w input of 100 μv at i-f center frequency. An equivalent amount of noise must be supplied to the i-f input of the Automatic Noise-Figure Indicator in order to maintain its calibration.)
3. Push the AUTO-NOISE FIGURE button, and read the noise figure on the meter.

3. MANUAL NOISE-FIGURE MEASUREMENT

When a continuous monitoring of the noise figure of an instrument is not desirable (or when a single measurement of greater accuracy is desired), the Automatic Noise-Figure Indicator can be used in conjunction with a calibrated precision attenuator (such as the AIL Type 30) for manual noise-figure measurements. Figure 4 is the bench setup for such a measurement. A manual measurement of noise figure is made in the following manner.

1. Interconnect the equipment as shown in Figure 4, and allow about 15 minutes for warming up.
2. Depress the DET. CURRENT AGC OFF and the NOISE GENERATOR OFF buttons.
3. Adjust the IF GAIN control for a convenient indication on the CURRENT scale. If the equipment under test has a variable-gain preamplifier, it is desirable to set it at or near its maximum gain. Observe the reading on the meter.
4. Note the i-f attenuator reading in db.
5. Press the NOISE GENERATOR ON button. (It may be necessary to ignite the noise source in automatic operation and then switch to manual operation.) This will inject the noise voltage into the system, and increase the meter deflection (an off-scale reading may result). Do not change the setting of the IF GAIN control.
6. Increase the attenuation until the meter reading returns to the originally observed (no-noise) value. The difference between the attenuator settings in steps 4 and 6 is the Y factor.
7. Using the Y-factor curve (Figure 5), obtain the actual noise figure of the equipment under test.

CAUTION

The presence of spurious responses of the receiver can modify the noise-figure reading (see paragraph 5a of this section).

4. CHECKS AND ADJUSTMENTS

Both the automatic and the manual methods of noise-figure measurement with the Noise Generator and the Automatic Noise-Figure Indicator are based on certain predetermined and

preset operating characteristics of these equipments. It is therefore desirable to make the following checks of these characteristics at periodic intervals.

a. NOISE-GENERATOR CURRENT

The gas-discharge lamp used in the AIL Type 70 Noise Generator is calibrated for a nominal current of 165 ma. Although a ±20 percent deviation in this current affects the noise output by less than 0.1 db, it is desirable for precise measurements to set this current to exactly 165 ma. Pushing the NOISE GENERATOR CURRENT button will indicate gas-lamp current. Adjustment of the lamp current can be made with the potentiometer (R35) located on the front of the chassis behind the panel.

NOTE

Under automatic operation, the noise-lamp current indication is one-half the peak current through the lamp because of the modulated mode of operation.

The NOISE GENERATOR ON-OFF buttons are used for the manual measurement of noise. Pushing the ON button ignites the argon lamp continuously, and pushing the OFF button shuts off the lamp. The oscillator-modulator circuits are inoperative during manual operation.

b. DETECTOR CURRENT WITH AGC OFF

When manual noise-figure measurements are made, the AGC is removed by depressing the AGC OFF button. In such a case, the i-f gain is adjusted manually, and the reference reading is noted on the 0 to 2.5 ma scale.

c. I-F GAIN

This adjustment is effective only when the AGC OFF button is depressed and is used for the manual noise-figure measurement. The i-f gain is adjusted for a convenient reading on the meter scale, depending on the gain of the equipment being tested.

5. PRECAUTIONS

In making noise-figure measurements, the following precautions must be observed if measurement inaccuracies are to be avoided.

a. BANDWIDTH EFFECTS

In making a noise-figure measurement, the overall noise bandwidth (including image, spurious, and other responses) determines the actual noise figure of the equipment under test. Thus the harmonic and spurious r-f responses may make the actual indicated noise figure better than the actual value. For instance, assuming the image response to be equal to the useful-signal response, the indicated noise figure obtained is 3 db lower than the actual noise figure. To obtain the true noise figure of the equipment under test, the effect of spurious image responses must be accounted for properly (see equation 2).

b. GENERATOR TEMPERATURE

The noise-figure measurement outlined in paragraph 3 of this section assumes that the generator temperature equals the temperature of the discharge. This is true if there is complete coupling of the noise output to the equipment under test. Any lesser coupling causes a reduction in the noise fed to the equipment under test. A measure of this coupling is the insertion loss of the fired generator. Using Figure 6, a correction to the final noise figure obtained can then be made. It should be pointed out that this correction is negligible for waveguide noise generators and is only used (if accuracies better than 0.25 db are required) for the helical noise source (AIL Type 70A) below 350 Mc.

c. NOISE-SOURCE TERMINATION

The accuracy of any noise-figure measurement depends on the proper termination of the Noise Generator. In the AIL Type 70A Noise Generator, a 50-ohm termination, connected to

either of the two type-N connectors, will ensure an SWR of less than 1.4. A length of 50-ohm lossy cable or a 50-ohm 20-db pad can also be used for this termination. This makes it possible to feed another signal (for calibration or alignment) in series with the noise input to the equipment under test.

d. TERMINATION TEMPERATURE

The effect of temperature variation of the noise-generator termination has little significance except when making low-noise-figure measurements of maximum accuracy. If, because of prolonged use or other factors, the termination temperature (normally assumed to be approximately 290 K) changes appreciably, a correction of the noise figure must be made as outlined in Section III.

SECTION III
THEORY OF OPERATION

1. GENERAL

The noise figure of a network is defined as the ratio of the available input-to-output signal-to-noise power ratios.

$$F = \frac{S_i/N_i}{S_o/N_o} \qquad (1)$$

where

F = the noise figure
S_i = the available signal input power
N_i = the available noise input power
S_o = the available signal output power
N_o = the available noise output power

Equation 1 implies that for an ideal (noiseless) network--one in which the signal-to-noise ratio is not degraded--$S_o/N_o = S_i/N_i$ and $F = 1$ (or 0-db noise figure). In actual cases, however, S_o/N_o is smaller because of the noise generated in the network. Using a standard noise source, S_i/N_i is known. Furthermore, the noise output of a receiver of available gain G can be written as

$$N_o = G(N_i + N_r)$$

where N_r = the equivalent internally generated noise power referred to the input terminals.

Since

$$\frac{S_i}{S_o} = \frac{1}{G}$$

the noise-figure formula (equation 1) can be written as

$$F = \frac{1}{G} \times \frac{G(N_i + N_r)}{N_i} = 1 + \frac{N_r}{N_i} \qquad (2)$$

This is the basis for the noise-figure measuring system of the AIL Type 72 Automatic Noise-Figure Indicator.

2. GAS-DISCHARGE LAMP

Gas-discharge lamps are sources of noise power because of the random motions of the electrons when the gas is ionized. The term "noise temperature" is related to the mean electron velocity in the gas and is referred to 290 K.

Thus, the relative excess noise temperature of a gas-discharge lamp, referred to 290 K (T_o), can be written as

$$t_d - 1 = \frac{T_d - T_o}{T_o} = \frac{T_d}{T_o} - 1 \qquad (3)$$

where

T_o = the reference temperature, assumed to be 290 K, and
T_d = the discharge or ionized temperature.

For a pure argon-discharge lamp, in which T_d is 10,100 K,

$$t_d - 1 = \frac{10,100}{290} - 1 = 33.8 \qquad (4)$$

The available relative excess noise power in decibels is therefore 10 log 33.8, or 15.28 db above thermal noise.

3. Y FACTOR

In determining the noise figure of a network or system, it is neither easy nor convenient to measure the generated noise directly. A practicable indirect method is to make two power-output measurements for two different input conditions.

The ratio of these two outputs, called the Y factor, is related to the noise figure as follows:

$$F = \frac{\left(\frac{T_d}{T_o} - 1\right)\frac{B_o}{B} - Y\left(\frac{T_1}{T_o} - 1\right) - \left(\frac{B_o}{B} - 1\right)\left(\frac{T_1}{T_o} - 1\right)}{Y - 1} \qquad (5)$$

where

B_o = the overall noise bandwidth (including image, spurious, and other responses),

B = the useful-channel bandwidth,

T_1 = the temperature of the termination in the noise-off condition,

Y = the ratio of power output with the generator on to the output with the generator off (equation 1).

Usually, T_1 is about the same as T_o. If B_o equals B also, equation 5 reduces to

$$F = \frac{T_d}{T_o} - 1/Y - 1 \text{ (in power ratio)} \qquad (6)$$

or

$$F_{db} = 10 \log\left(\frac{T_d}{T_o} - 1\right) - 10 \log(Y - 1). \qquad (7)$$

When extreme accuracy is desired, equation 5 must be used in order to take account of temperature variation, image response, etc. Figure 5 gives the values of F_{db} in terms of Y (from equation 7).

4. NOISE-LAMP MODULATOR

In an automatic noise-figure indicating system, a means must be provided to periodically shut off the Noise Generator. This is accomplished in the AIL Type 72 by the square-wave modulator. A 300-cps square-wave generator keys

the noise lamp on and off. The output of the video detector consists of a square wave (as shown in Figure 2) whose maximum level corresponds to power output with the Noise Generator on, and whose minimum level corresponds to receiver noise alone (Noise Generator off). The peak-to-peak value of this square wave is therefore an indication of the noise figure of the network under test.

5. MODULATION FREQUENCY AND NARROW-BAND FILTER

As shown in Figure 2, the square-wave output contains a superimposed fluctuation because of random low-frequency noise. For small noise figures, where the peak-to-peak amplitudes of the square wave are large, the instantaneous error introduced in V_1 by the fluctuation is rather negligible. For poor noise figures, however, where V_2 is not sufficiently greater than V_1, this fluctuation assumes an appreciable relative magnitude. The narrow-band filter, which is tuned to the modulation frequency, reduces this fluctuation to a negligible level so that, for a 20-db noise-figure measurement (the maximum noise figure that can be measured with the AIL Type 72 Automatic Noise-Figure Indicator), the meter fluctuation is only approximately 0.25 db, or a little over 1 percent. A sharper filter could increase the range of the Automatic Noise-Figure Indicator; changing to a sharper filter is not practicable, however, because, for an extension of the range to 25 db, a 10:1 reduction in filter bandwidth would be required. This entails elaborate and complex stabilizing circuits for the multivibrator beyond the point that could be justified by a slight extension of the noise-figure range.

At first glance, it would seem that increasing the switching frequency sufficiently would automatically minimize the effect of these fluctuations. However, since the de-ionization time of the argon lamp is finite, the switching frequency must be kept low enough to make the de-ionization time relatively

insignificant. The incremental noise generated during the Noise-Generator off time by the slow de-ionization is equivalent to raising the minimum level (V_1 in Figure 2) and thus apparently degrading the noise figure of a network.

6. CIRCUIT DESCRIPTION

a. NOISE-LAMP SWITCHING

Figures 2 and 7 are the block and schematic diagrams of the Automatic Noise-Figure Indicator. A multivibrator operating at approximately 600 cps triggers a square-wave generator. The output of the generator is fed to a differential amplifier (V3) that produces both positive and negative pulses for simultaneous triggering of both the shunt modulator (V5), which ignites the gas tube, and the series modulator (V4), which opens or closes the return path of the noise tube.

When the negative-going pulse is applied to the grid of V5, the tube cuts off. As a result of the high reactance in the plate circuit, an instantaneous potential of about 1500 to 2000 volts is developed, which is sufficient to ionize the argon lamp. With the triggering of the shunt tube, the positive-going pulse from the differential amplifier drives the series modulator (V4) into conduction. This tube is a dual triode (type 6080) with both sections in parallel to ensure an adequate sustaining current for the noise lamp. At the end of the on time of the Noise Generator, V4 cuts off, thereby breaking the noise-lamp return path. The noise output then decreases to zero, and V5 again conducts.

b. I-F AND VIDEO AMPLIFIERS

The i-f and video amplifiers are conventional circuits. The i-f amplifier is synchronously tuned and has a pass band of about 1.5 Mc. The i-f gain of the peak-to-peak signal is automatically maintained constant by the AGC loop from the video

detector to the first four stages. This enables calibration of the current for a gain check. The output of the video amplifier feeds the narrow-band filter. The cathode-follower stage after the filter isolates the meter circuit and prevents it from loading the tuned filter.

c. SWITCHING

The push-button switching arrangement of the Automatic Noise-Figure Indicator is automatic and practically foolproof. The POWER ON-OFF push-button switch is independent of all other switches. The remaining push-buttons automatically select the manner of operation. For example, when the AUTO NOISE FIGURE button is depressed, the manual lamp circuits are ineffective and the modulation stages are on. Similarly, when the DET. CURRENT AGC ON button is depressed, the manual gain control is inoperative.

Table I lists the possible circuit and function arrangements that exist for certain settings of buttons; however, the information in the table is not intended as an operating procedure.

d. ADJUSTMENTS

There are four presetting or calibration adjustments in the noise-figure portion of the Automatic Noise-Figure Indicator: (1) frequency adjustment of the oscillator, (2) duty-cycle adjustment of the shunt modulator, (3) noise-lamp current adjustment in the series modulator, and (4) meter calibration.

(1) OSCILLATOR ADJUSTMENT

Frequency-adjustment control R5 (available through the side panel) in the grid of the multivibrator (V1) makes it possible to filter random fluctuations of the square-wave output. Since the filter (L6 and C18) in the input to the video amplifier (V14) is fixed, R5 becomes a peaking adjustment (the absolute multivibrator frequency is not critical).

TABLE I
ARRANGEMENT OF SWITCHING SYSTEM

Button(s) Depressed	Meter Reads	Function Available	Function Not Available
AUTO-NOISE FIGURE	Noise figure	Automatic noise-figure reading.	Manual control of i-f gain. Noise Generator on. Noise Generator off.
AUTO-NOISE FIGURE DET. CURRENT AGC ON	Detector current		Manual control of i-f gain. Noise Generator on. Noise Generator off.
AUTO-NOISE FIGURE DET. CURRENT AGC OFF	Detector current	Manual control of i-f gain.	Noise Generator on Noise Generator off.
AUTO NOISE FIGURE NOISE GENERATOR CURRENT	Lamp current		Manual control of i-f gain. Noise Generator on. Noise Generator off.
DET. CURRENT AGC ON	Detector current	Noise Generator on. Noise Generator off.	Manual control of i-f gain.
DET. CURRENT AGC OFF	Detector current	Manual control of i-f gain. Noise Generator on. Noise Generator off.	
NOISE GENERATOR CURRENT	Lamp current	Noise Generator on. Noise Generator off.	Manual control of i-f gain.

(2) DUTY-CYCLE ADJUSTMENT

The duty-cycle adjustment (R26) provides an input control to the shunt modulator. Since the meter calibration was based on a 0.5 duty cycle, any deviation from such a ratio would adversely affect the accuracy of the noise-figure measurements. This adjustment (R26) allows the current through the shunt modulator to be made slightly larger than the normal lamp current, thus developing a quenching impulse that aids in the de-ionization of the gas tube. When properly adjusted, the top of the current pulse, as viewed across the 10-ohm resistor in the cathode of the series tube (V4) will have a negative slope of about 5 percent. Across the 10-ohm resistor in the cathode of the shunt modulator (V5) the top of the current-pulse will have a positive slope of about 5 percent. The duty-cycle adjustment needs to be made only once when initially checking out the instrument.

(3) NOISE-LAMP CURRENT ADJUSTMENT

Since one of the factors that determines the noise output of the argon gas-discharge lamp depends on the degree of ionization, the noise-lamp current adjustment (R35) enables setting the lamp current to the specified value (165 ma) for which it was calibrated. This adjustment needs to be made only once when initially checking out the instrument.

(4) METER CALIBRATION

The meter calibration control (R64) is a compensating adjustment for correcting variations in video-amplifier gain and variations due to aging, tube component replacement, etc. This adjustment may have to be made periodically, depending on the conditions under which the equipment is used.

SECTION IV
MAINTENANCE

The maintenance of the Automatic Noise-Figure Indicator is similar to that of any piece of electronic equipment of medium complexity. However, since this equipment will invariably be used with a Type 70 Noise Generator, information on maintenance of the Noise Generator is also included.

1. NOISE GENERATOR

The argon gas-discharge lamp has a long life expectancy. However, it is conceivable that a defect (leak or breakage) can develop, causing the tube not to fire. Before replacing the gas tube, the high-voltage contacts to the tube should be carefully inspected. Any looseness, corrosion, or evidence of arcing may be responsible for the failure of the tube to ignite. If these factors are not responsible for the failure, the argon lamp tube itself or the mount assembly may be defective. In the case of the Type 70A Noise Generator, it is not advisable to attempt to repair the internal structure of the generator; the generator should be returned to this Laboratory for repair and recalibration.

2. AUTOMATIC NOISE-FIGURE INDICATOR

Figure 7 is the schematic diagram of the Automatic Noise-Figure Indicator; this diagram also shows voltage data and waveforms.

3. I-F AND VIDEO AMPLIFIER

All tuned circuits of the i-f strip are aligned for maximum output at the intermediate frequency. To prevent AGC action during alignment, the AGC OFF button should be depressed and the IF GAIN control should be advanced to maximum (or near

maximum) setting. Operating voltages (no-signal condition) for the various tubes are given alongside the pertinent socket pins.

4. SWITCHING CIRCUITS

The automatic switching system depends on mechanical interlocking between all sections of a set of push-buttons. The POWER ON-OFF pair of buttons makes up one set, the NOISE GENERATOR ON-OFF pair of buttons makes up another set, and the center group of four buttons makes up a third set. In each set, depressing one button releases any other button or buttons that may have been depressed. In addition, there is electrical interlocking, so that depressing the AUTO-NOISE FIGURE button automatically deactivates the manual NOISE GENERATOR ON-OFF buttons. Conversely, depressing any button in the center group will mechanically release the AUTO-NOISE FIGURE button, set the equipment for manual operation, and allow use of the various functions listed in Table I.

FIGURE I. AIL TYPE 72 AUTOMATIC NOISE-FIGURE INDICATOR

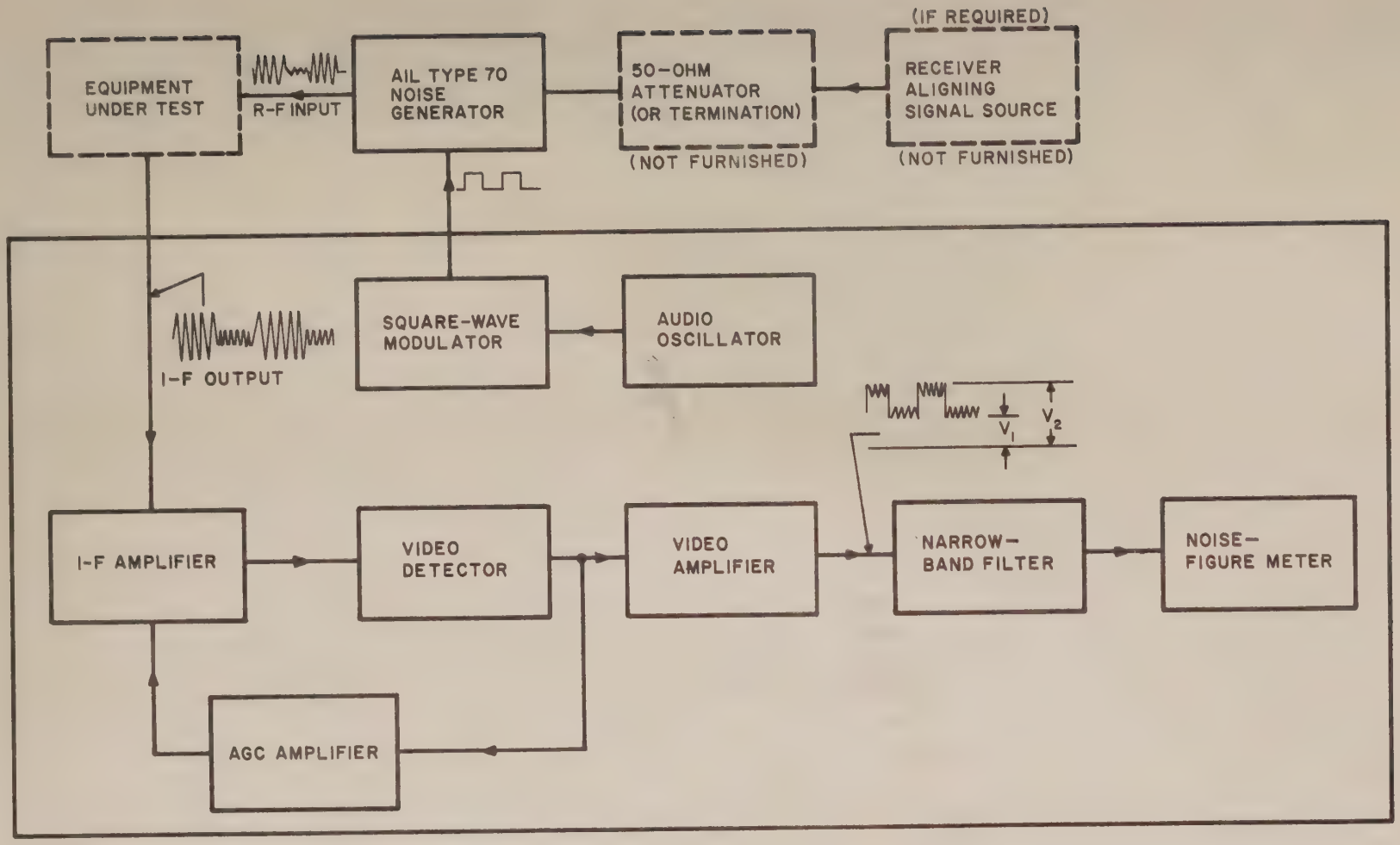

FIGURE 2. AUTOMATIC NOISE-FIGURE INDICATOR, FUNCTIONAL BLOCK DIAGRAM

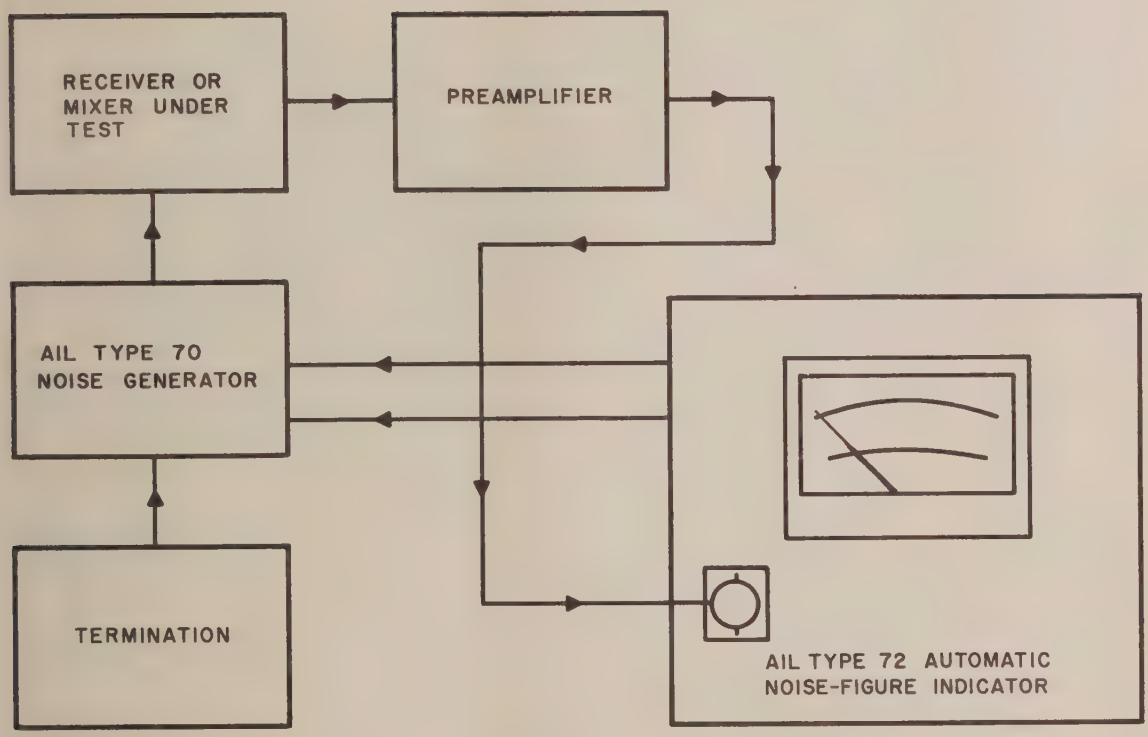

FIGURE 3. TYPICAL BENCH SETUP USING AUTOMATIC NOISE-FIGURE INDICATOR AND NOISE GENERATOR FOR AUTOMATIC NOISE-FIGURE MEASUREMENT

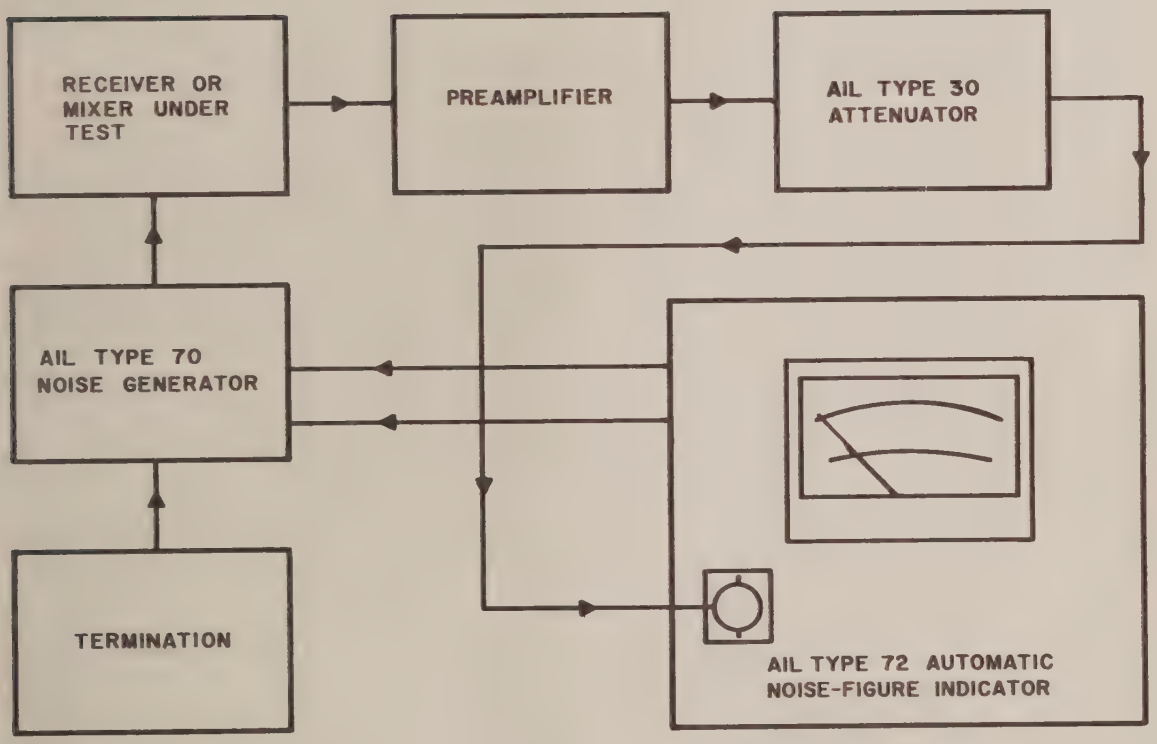

FIGURE 4. BENCH SETUP FOR MANUAL NOISE-FIGURE MEASUREMENT

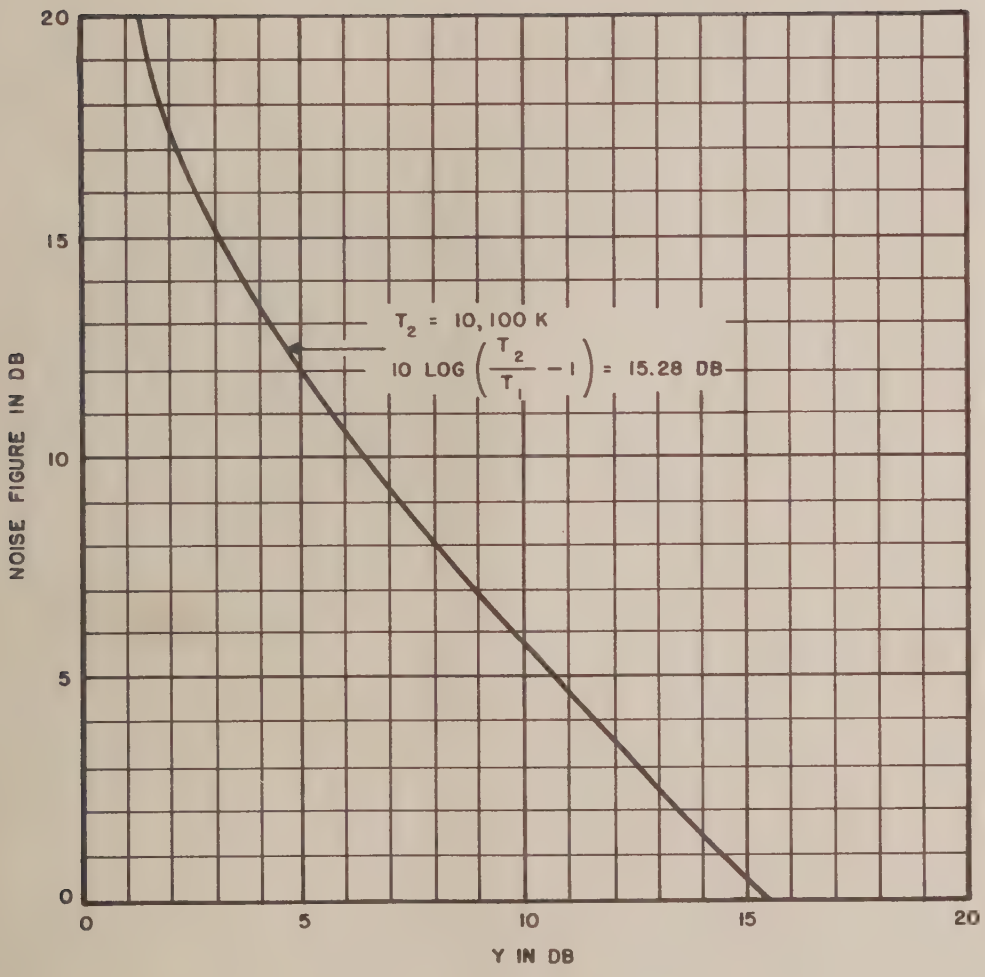

FIGURE 5. Y FACTOR VS NOISE FIGURE FOR 15.28-DB NOISE SOURCE

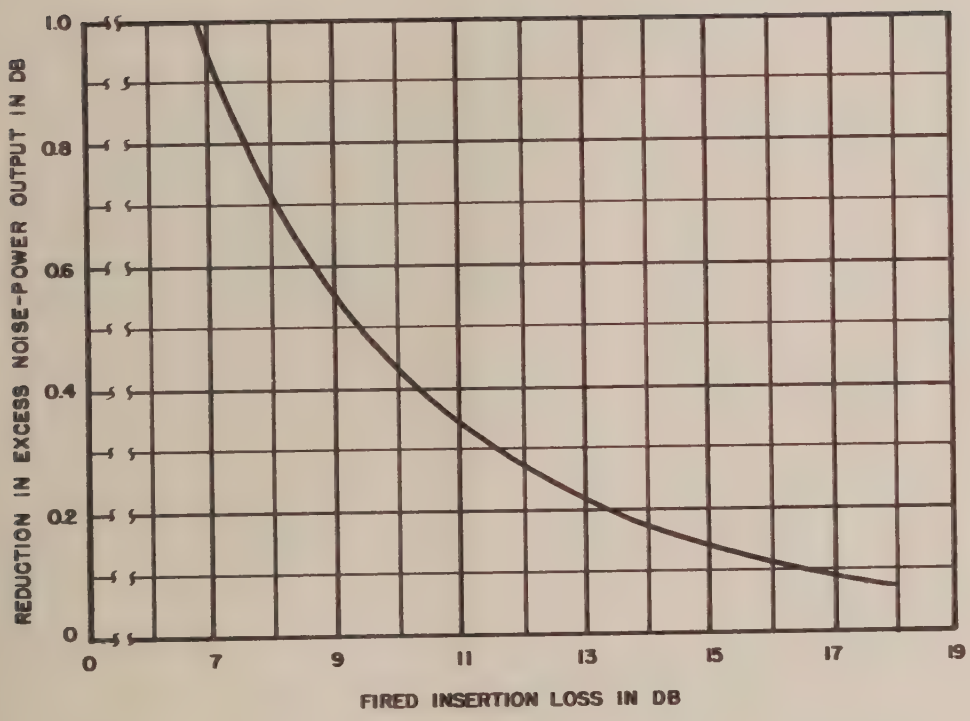

FIGURE 6. REDUCTION IN EXCESS NOISE-POWER OUTPUT AS A FUNCTION OF FIRED INSERTION LOSS

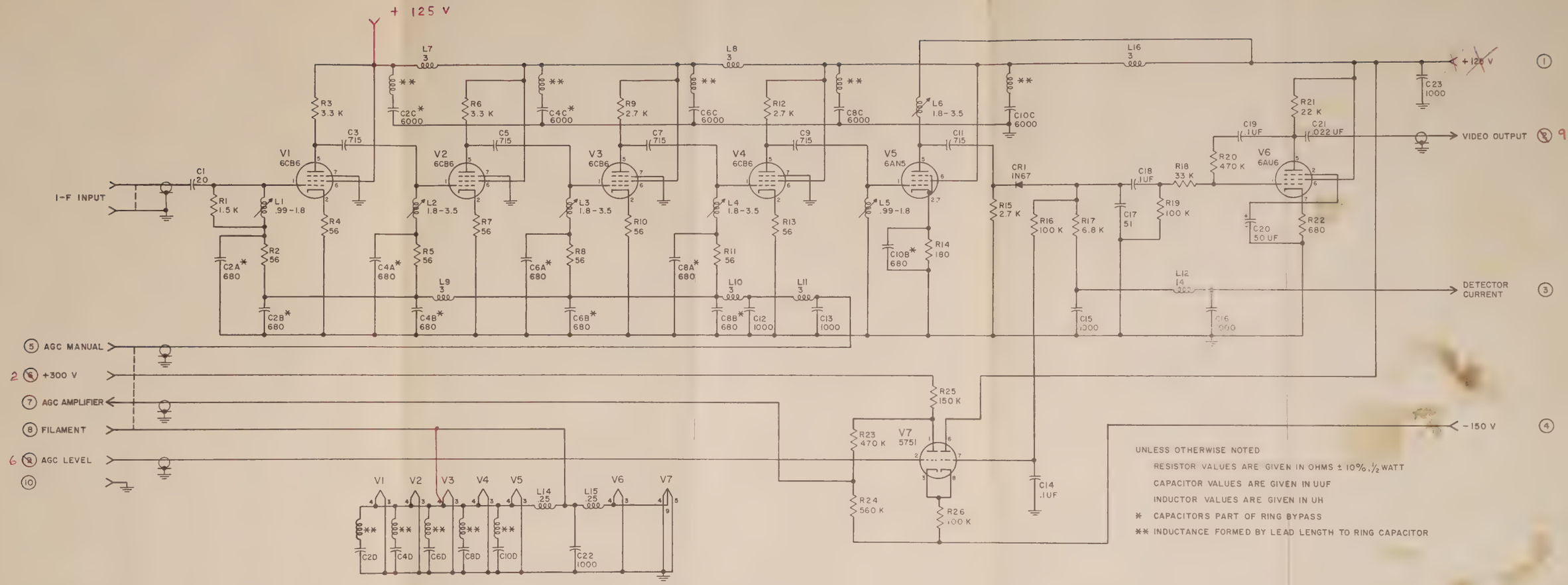

FIGURE 7. AUTOMATIC NOISE-FIGURE MEASURING EQUIPMENT, SCHEMATIC DIAGRAM

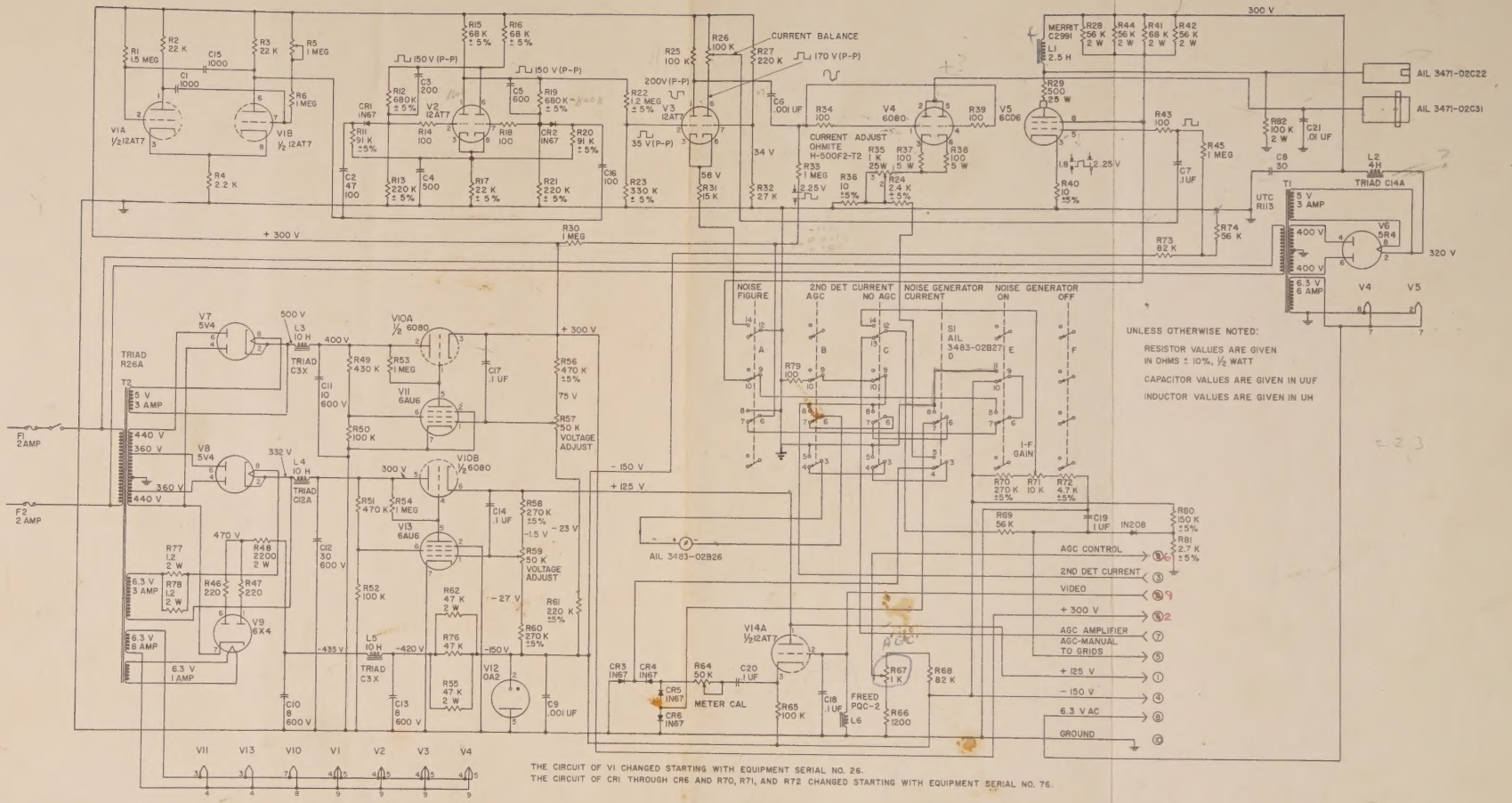

FIGURE 7. AUTOMATIC NOISE-FIGURE MEASURING EQUIPMENT, SCHEMATIC DIAGRAM